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Summaries

Optimal disease eradication

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When is it optimal to eradicate an infectious disease? Using a dynamic model of the optimal control of an infectious disease, we derive the conditions under which eradication will be optimal. The alternative to eradication is control of the disease, which requires ongoing intervention. Eradication, by contrast, is permanent. If eradication succeeds, control by vaccination is no longer needed. To eradicate a disease, the level of control has to be increased in the short term. If eradication succeeds, however, then it will yield a dividend in the long run in terms of both avoided infections and avoided vaccination costs. Eradication is essentially an investment decision.

To analyze this decision, we construct an economic model built upon the foundation of an underlying epidemiology model. The latter model is of a dynamical system involving the pathogen and a human population. The standard model in the mathematical epidemiology literature only allows eradication to be achieved in the limit as time goes to infinity. We therefore modify this model to enable eradication to be achieved in finite time. This modification is essential. Without it there cannot exist an eradication dividend.

We show that the optimal program requires either a low vaccination rate or eradication. A high vaccination rate is never optimal. This is because, if it were optimal to control a disease at a high level, then with only a little additional effort the disease could be eradicated, yielding a huge dividend. Assuming vaccination costs are linear, we obtain a particularly stark result: it is optimal either not to vaccinate at all or to eradicate the disease. Ongoing control is never optimal when costs are linear.

Our analysis yields a benefit–cost rule for when eradication is optimal, and we apply this to the current effort to eradicate poliomyelitis. Previous studies have compared the costs and benefits of polio eradication but they did not compare eradication to the alternative of optimal disease control. Our approach offers a more appropriate framework for analysis. We find that polio eradication would be economically desirable – provided, that is, that eradiation of this disease were technically feasible. Our discussion of the current eradication effort points to a number of problems, mainly related to the vaccines used to eradicate the disease and the possibility that the virus might re-emerge from use of the live-attenuated oral vaccine. Should polio eradication fail, the resources spent trying to eradicate polio will largely have been wasted. Our model is deterministic, but in the real world eradication is the ultimate high stakes game.

A cost analysis of alternative culling strategies for the eradication of classical swine fever in wildlife

LUCA BOLZONI and GIULIO A. DE LEO

Recent epidemics of avian influenza, foot-and-mouth disease, rabies, and classical swine fever have brought to public attention the issue of disease eradication in wildlife, as the consequences of pathogen spillover from wildlife reservoir to livestock and human population can be very dramatic. The reduction of population density by hunting or culling (i.e., selective removal of animal) is often perceived as the simplest and most effective way to control diseases in wild populations. Simple mathematical models show that when population density drops below a critical threshold level, as a consequence of culling or hunting, the pathogen cannot persist in the population because of a reduction in the contact rate between infective and susceptible individuals. However, these models usually assume that culling or hunting rate are constant in time. Moreover, the analysis of direct and indirect costs of culling (or of not culling) has been usually neglected in the literature of wild animal diseases.

In the present work, we investigate the effect of more realistic, time-variant culling strategies by explicitly using a cost–benefit framework. Specifically, we analyse a set of simple control policies that require only a few control variables to be monitored, such as host density, number of carcasses and disease prevalence. In fact, national and local wildlife services are characterized by administrative structures and are constrained by legislative regulations that prevent them from applying complex adaptive policies of eradication, especially (but not exclusively) in developing countries where health authorities have limited funds and limited intervention capacity.

Classical swine fever in wild boar populations has been taken as a reference disease because of its potential economic impact on pig farming in industrialized and developing countries.

Direct and indirect costs of disease spread have been estimated with reference to two broad categories: (i) direct costs associated with the culling activity and (ii) sanitary costs associated with the potential spillover of the pathogen from the wildlife reservoir to the farm, estimated in terms of cost of slaughtering pigs and carcass disposal, disinfections, temporary shut down of commercial activities, cost of farms repopulation, etc. In general, low culling rates obviously imply low culling costs but high sanitary costs if an infection reaches the pig farms. On the other hand, high culling rates significantly reduce the risk of pathogen spillover and the consequent damages, but imply significant culling costs.

For each type of eradication strategy analysed in this work, we have identified the optimal policy as the one that allows public authorities to minimize the sum of culling and sanitary costs. A sensitivity analysis has been performed for different assumptions on the shape of costs functions.

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We show that time flexible control strategies based on simple control parameters can be significantly more cost-effective than classical eradication strategies based on a constant culling rate.

Optimal harvesting during an invasion of a sublethal plant pathogen

HOLLY GAFF, HEM RAJ JOSHI and SUZANNE LENHART

Plant diseases are destructive to cash crops throughout the world, resulting in potentially devastating financial losses. For example, sweet corn is susceptible to both common smut (*Ustilago maydis*) and common rust (*Puccina sorghi*). These types of diseases are typically first discovered in a single location within the field, and the disease will then spread out to the rest of the field. The question that arises is how to maximize the profit for that crop in the face of an infection. Traditional harvesting waits until the end of the growing season to harvest and sell the crop under the assumption that profit will increase with the age of a healthy plant. However, with a spreading disease, the removal of infected plants earlier in the season may actually increase overall profit if the removal results in reduced disease burden across the entire field. A mathematical model is employed to identify this balance. Using a mathematical technique called optimal control, the harvesting scheme that maximizes profits can be found. The results of these calculations show that removal, or culling, of both plants infected with disease as well as within a defined distance around that area, can greatly reduce loss of profit. The distance that is culled around the infected area for optimal profit is found to be approximately three times the dispersal distance of the disease. While the simplicity of this system limits direct applications, there is a proof of principle that the application of optimal control of a mathematical model can provide guidance to identify strategies that minimize the loss of profits.

Infectious disease, development, and climate change: a scenario analysis

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The incidence of infectious diseases, such as diarrhoea and malaria, would increase with climate change but decrease with development. The relative strengths of these tendencies are tested in a scenario analysis. Unfortunately,

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good data on infectious diseases are lacking, particularly in the poorest countries where the incidence is highest. Instead, we use data on infant mortality. Infant mortality and infectious disease incidence are closely correlated where there are data. Difference in infant mortality can be explained by difference in per capita income, in literacy rates, and in absolute poverty rates. We use a scenario of rapid economic growth. Economic growth implies rising income, increasing literacy, falling poverty, and rising carbon dioxide emissions. Under these assumptions, the number of malaria deaths would first rise because of population growth and climate change. The same holds for diarrhoea, dengue fever, and schistosomiasis. The same qualitative pattern emerges for a wide variety of parameters and scenarios. However, the time and level at which the number of deaths peaks, is very uncertain. Climate change is important for infectious disease in the medium term, but the effect of climate change is dominated by that of development in the long term. As climate policy would affect climate change only with a long delay, development is the preferred policy to reduce the impacts of climate change on infectious disease. Development would also have short-term benefits on health care in poor countries. However, these results should be interpreted with caution, as development has proved to be elusive in many countries and development aid has had mixed success.

Economic incentives and mathematical models of disease

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Mathematical models of infectious diseases such as malaria, HIV/AIDS, and schistosomiasis have given us important insights into how diseases are transmitted and how best to control them. More recently, economists have become interested in studying infectious diseases in order to understand how individuals respond to the risk of infection and how best to design and allocate resources for public health programs of prevention and treatment. Despite their common use of mathematics, and pursuit of similar questions, rarely have economists, mathematical epidemiologists, and biologists collaborated in understanding how diseases evolve and spread.

In this paper we explore the benefit of incorporating simple economic principles of individual behavior and resource optimization into epidemiological models. We discuss the interplay between human behavior and economic incentives and suggest important directions for future collaborations, including incorporating assumptions of rational behavior, considering externalities, and taking into account global disease commons. We conclude with a discussion where we suggest that greater collaboration across the two fields could generate more useful models to guide policy as well as enhance understanding of how diseases and humans interact.